VERY HIGH TEMPERATURES.[1]

EXACTLY a century ago this month Michael Faraday entered the Royal Institution for the first time. He was then a youth of twenty, in the last year of his apprenticeship to a bookbinder in Blandford Street. Among the meagre records we possess of Faraday's early life we find the following:—

"I had the good fortune, through the kindness of Mr. Dance, who was a customer in my master's shop and also a member of the Royal Institution, to hear four of the last lectures of Sir Humphry Davy in that locality. The dates of these lectures were February 29, March 14, April 8 and 10, 1812."

It was Faraday's habit to occupy the seat in the gallery over the clock. He made very full notes of the lectures, and afterwards wrote them up, indexed and bound them with his own hands into a volume of 300 pages, which is now preserved at the Royal Institution.[2]

Some months later Faraday writes:—"Under the encouragement of Mr. Dance I wrote to Sir Humphry Davy, sending, as a proof of my earnestness, the notes I had taken of his last four lectures. The reply was immediate, kind, and favourable."

In March, 1813, apparently largely on the strength of the impression made upon Davy by this volume of notes, Faraday was engaged as assistant in the laboratory of the Royal Institution at a salary of 25*s*. a week, with two rooms at the top of the house.

The first lecture of Davy's course referred to was on "Radiant Matter," and dealt, among other things, with the action of electric sparks on gases. Ever since Volta's discovery in 1800 Davy had been occupied with the study of the pile and the effect of the new currents in producing heat and chemical change, thus leading up to his decomposition of the fixed alkalies and the isolation of potassium in 1807.

Following on this discovery, Davy proposed that a fund "should be raised by subscription for the construction of a large and powerful battery, worthy of a national establishment, and capable of promoting the great objects of science, and that this battery be erected in the laboratory of the Royal Institution." The sum required, a little more than 500*l*., was soon got together, and at the concluding lecture of the 1812 season the battery was put in action for the first time. We read in Davy's "Elements of Chemical Philosophy," iv., p. 110, an account of how he applied the battery to the running of an electric "arch" between two carbon rods. Parts of Davy's battery are still preserved at the Royal Institution.[2]

I begin my lecture thus merely to emphasise once more the truth of the adage of 3000 years ago: "There is no new thing under the sun."

In 1912, when considering the subject of "very high temperatures," we can claim, comparatively speaking, to be capable of little more than Davy accomplished a century ago. In his arc he melted all the most infusible materials known to him, including lime and magnesia, which are among the most refractory materials in use at the present day.

Turning now from the historic to the present aspect of our subject, permit me to begin with a few elementary considerations as to our conception of temperature. I think I am correct in saying that everyone has some idea in his own mind of a temperature scale, a kind of intuition which is generally a fairly useful one for practical purposes. Probably I am not exaggerating when I say that even men of science, who always think for their professional purposes of temperatures on the centigrade scale, find themselves obliged to convert to Fahrenheit for an idea of the temperature of a room or of a summer's day.

I have endeavoured to give a graphic representation (Fig. 1) of the temperature scale as we know it, both in centigrade and Fahrenheit degrees. You will notice the smallness of the interval between the extreme temperatures that prevail in the arctics and the tropics, and how restricted the "cold" region down to absolute zero is compared with the possibilities in the other direction. While, on the one hand, Kammerlingh Onnes by the evaporation of liquid helium under low pressure has succeeded in getting during the last few weeks to within 1·1° C. of absolute zero, the highest recorded terrestrial temperature—that of an electric arc under high pressure—falls short of the sun's estimated temperature by some 2000° C.

Some landmarks in our available range of temperature are given in Table I. It may be remarked that the three substances last quoted in the table are all in extensive use for electric lamp filaments.

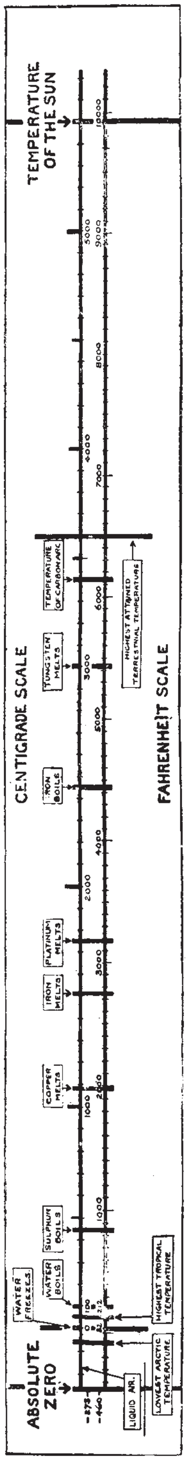

FIG. 1.

TABLE I.—*Various Temperatures.*

	Deg. C.
Absolute zero	−273
Helium boils (0·2 mm.)	−272
„ „ (760 mm.)	−269
Hydrogen boils	−253
Oxygen boils	−183
Carbonic acid boils	−78
Mercury freezes	−39
Water freezes	0
Water boils	100
Tin melts	232
Lead melts	327
Mercury boils	357
Zinc melts	419
Sulphur boils	445
Aluminium melts	657
Common salt melts	801
Zinc boils	918
Silver melts	961
Gold melts	1062
Copper melts	1083
Cast-iron melts	about 1100
Pure iron melts	1500
Fire bricks soften	1400–1800
Silica softens	1500–1600
Platinum melts	1750
Silver boils	1950
Tin boils	2270
Copper boils	2310
Lime and magnesia melt	about 2400
Iron boils	2450
Tantalum melts	about 2900
Tungsten melts	„ 3000
Carbon melts	„ ?

Table II. gives examples of various flame temperatures which we have at our disposal.

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[1] Abridged from a discourse delivered at the Royal Institution on February 9 by Dr. J. A. Harker, F.R.S.

[2] Exhibited on the lecture table.

TABLE II.

Temperatures obtainable in :—

	Deg. C.
Bunsen burner flame	1100–1350
Méker burner flame	1450–1500
Petrol blow-lamp flame	1500–1600
Oxy-hydrogen flame	about 2000
Oxy-acetylene flame	,, 2400
Electric arc	,, 3500
Electric arc (under pressure)	,, 3600
Sun	,, 5500

Some of the methods for measuring temperature with their limitations are briefly recapitulated in Table III. I have only time to refer to one or two points. We have recently had the opportunity at the National Physical Laboratory of subjecting a number of mercury in silica thermometers to a critical examination. These thermometers, which are made in England, possess in a high degree the qualities of constancy, large range, and such complete freedom from temporary zero change, that I feel safe in prophesying they will inevitably replace the present international standards, which are made of verre dur.

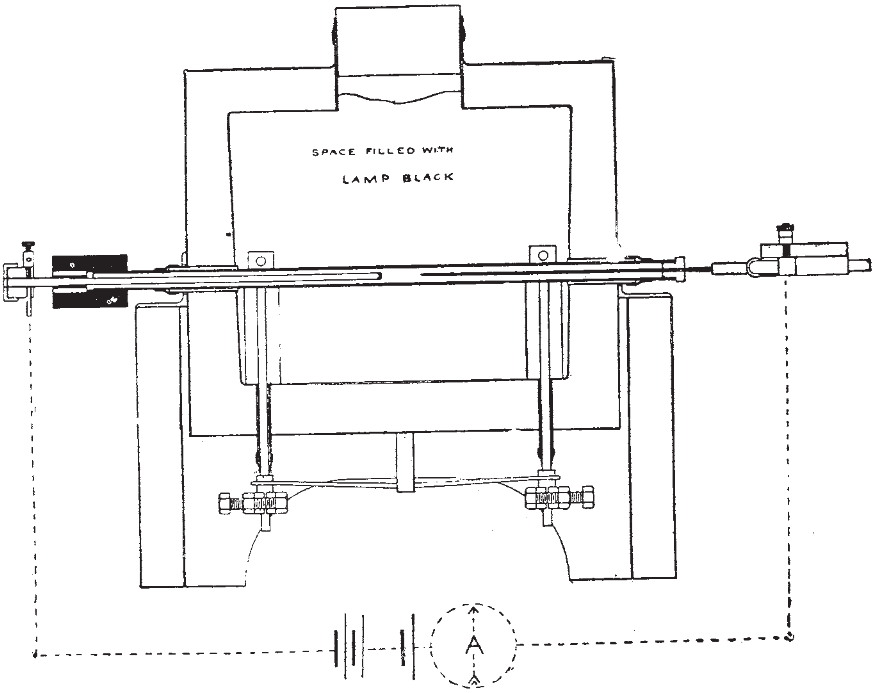

FIG. 2.—Small model straight carbon-tube furnace.

TABLE III.—*Some Indication of the Present Range of Temperature-measuring Instruments.*

Method.	Range in Degrees C.	
	Practical.	Extreme.
Expansion thermometers—		
Gas thermometer ...	Up to 1200°	- 272° to 1550°
Mercury in glass ...	- 39° ,, 500°	- 44° ,, 575°
Mercury in silica ...	- 39° ,, 600°	- 44° ,, 700°
Electrical thermometers—		
Platinum resistance ...	- 100° ,, 1100°	- 250° ,, 1400°
Thermocouples :		
— platinum alloys ...	300° ,, 1400°	Up ,, 1750°
— base metals ...	- 100° ,, 1100°	- 250° ,, 1200°
Total radiation pyrometers	500° ,, 1400°	No upper limit
Optical pyrometers... ...	600° ,, 3500°	No upper limit

In regard to high temperatures, most of us rely to some extent on colour in estimating temperature. Table IV. gives a very fair notion of the temperature we may reasonably associate with the colour of a fire or muffle furnace (experiment shown). The intensity of the light varies according to well-known laws which have been studied up to sun's temperature. If we know the law of variation we can measure the temperature by the use of some kind of photometer—which is what all optical pyrometers are.

TABLE IV.—*Temperature and Colour of a Fire.*

Colour.	Cent.	Fahr.
"Grey," lowest discernible temp.	About 450	About 850
Very dull red	,, 500°	,, 950°
Dull red	,, 700°	,, 1300°
Cherry red	,, 900°	,, 1650°
Orange	,, 1100°	,, 2000°
White	,, 1300°	,, 2400°
Dazzling white	Above 1500°	Above 2750°

For obtaining really high temperatures electric furnaces are our only resort. Small gas furnaces can reach 1600° with difficulty; large industrial furnaces attain 1800° C. in some instances.

Mr. Cook, of Manchester, has kindly lent me for this occasion a number of electric furnaces. These are constructed by winding tubes of fire-clay or alumina with nichrome or platinum wire or strip: the external lagging is of kieselguhr. Steady temperatures up to about 1000° and 1200° C. respectively can readily be got with power from a commercial circuit of 100 or 200 volts. With thicker wires and current at lower voltage these upper limits can be appreciably extended.

For higher temperatures we have to make use of carbon or graphite, and electric heating was first applied by such means in the form of the arc furnace. Such a furnace has many inconveniences—the heating is intensely local, and there may, for example, be a gradient of 2000° C. in a single inch. There is practically no temperature control, and there is every possibility of the final product becoming largely contaminated with carbon. Most of the early isolated so-called elements have since proved to be largely carbides.

Resistance heating is usually much more convenient, and this is the principle of carbon-tube furnaces, some essential features of which were employed by Prof. Dewar many years ago. They will stand rough use, and are much more controllable than the arc furnace. It is as easy to control a temperature of 2500° C. as one of a red heat.

Such furnaces usually have their end-terminals water-cooled, and are surrounded by lagging of lamp-black or charcoal

The furnace tubes are either straight if made of carbon (Fig. 2), or spiral if made of Acheson graphite (Fig. 3). In the latter case they are provided with an internal liner tube of carbon. There is no special difficulty in cutting the spirals from the solid; graphite, unlike amorphous carbon, is an extremely tractable substance to machine.

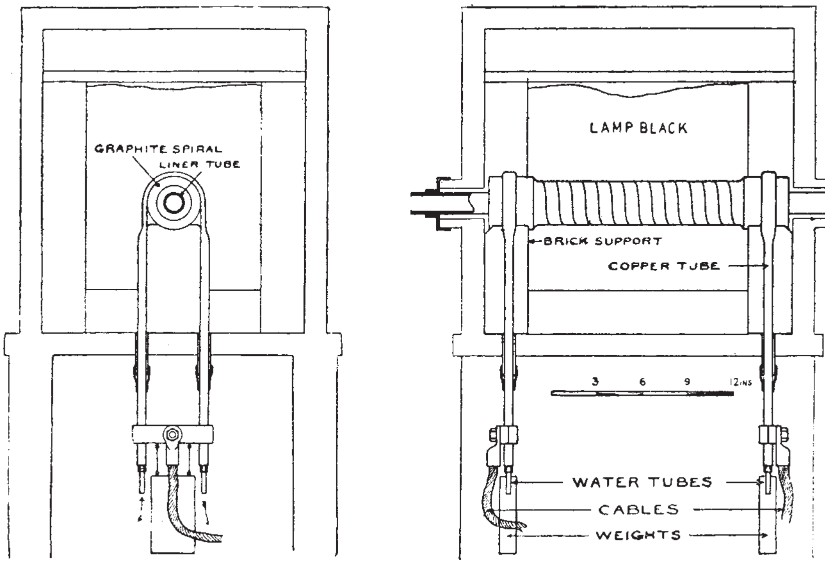

FIG. 3.—Carbon-tube furnace with graphite spiral heater.

We have used these carbon resistance furnaces a great deal at the National Physical Laboratory, and Mr. Greenwood, at Manchester, carried out his experiments on boiling metals by the aid of such a furnace. The boiling of a metal forms a not impossible lecture experiment, and a projected image of the surface of boiling tin (shown) displays all the usual phenomena of ebullition. The heating up of carbon is somewhat strikingly shown by passing a heavy current through a thin broad carbon strip provided with water-cooled terminals (experiment shown). The lines of flow from one terminal to the other are well illustrated at one stage of the heating.

Among other methods of electric heating are the induction furnace, which is of great value in refining crude materials, and the flame spark, in which it is possible to volatilise so refractory a substance as an incandescent gas mantle.

Some time ago I endeavoured at the National Physical Laboratory to make a furnace for very high temperatures without employing carbon.[3] The introduction of the Nernst lamp was suggestive. It was found that a great number of substances could be made to act like a Nernst filament, *e.g.* a piece of the stem of a churchwarden pipe, if sufficiently strongly heated, can be made to conduct electricity well enough to become incandescent. Carborundum crystal behaves similarly, and requires no initial heating (experiment shown); in this case the temperature can be raised high enough to volatilise off the silicon, which burns, forming a cloud of silica. A cascade furnace was constructed on these lines: a tube made up of zirconia and a little yttria was raised by means of an insulated nickel winding to 500° or 600°, at which temperature the tube conducts sufficiently well to enable a heating current to be passed through it. There is no difficulty in melting platinum, for example, in such a furnace using a quite small heating current (about 2 amps.). A zirconia tube from such a furnace was taken out after it had been run for six months or so; it was then found to be quite translucent. The possibility of constructing in such a way refractory gas-tight materials at once suggested itself and we proceeded to manufacture "pottery" at high temperatures. Great difficulties have been encountered in the experiments. Whereas, for example, the potter in baking his wares at temperatures up to 1300° C. looks for a shrinkage of 5 per cent. or so, we were confronted with a shrinkage of 37 per cent. with tubes baked at temperatures up to about 1800° C. For the purposes of the fritting we employed carbon-tube furnaces of one of the types mentioned above. Now it sometimes happened that the outer surface of the zirconia tubes, instead of having the white and hard appearance of the rest, was found to be carburised and crumbly after baking. The action was not merely superficial, but extended to an appreciable depth. On the other hand, the inner surface of the tube, though freely open to the furnace atmosphere,

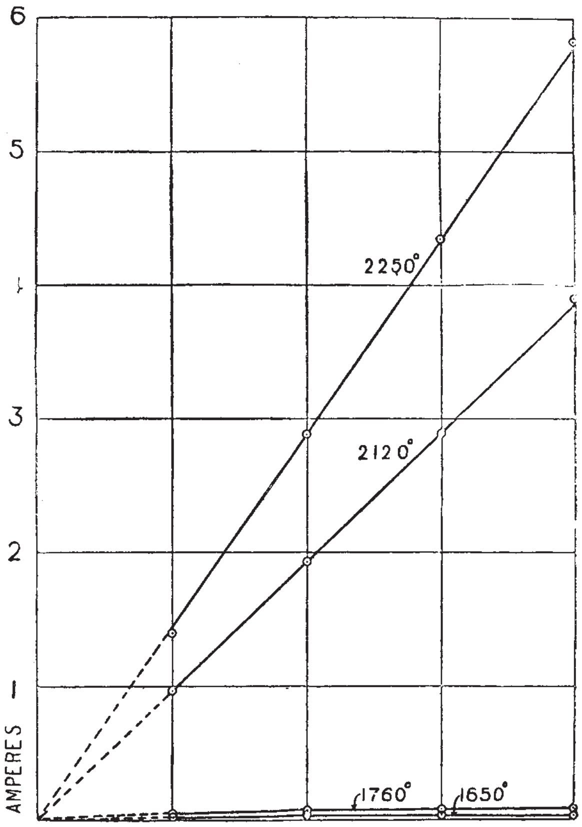

FIG. 4.—Relation between ionisation current and applied potentials for 1 cm. gap between the electrodes.

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[3] Proc. Roy. Soc., vol. 76 A, p. 235, 1905.

was much less affected. The blackening occurred to a much less extent if the tube was shielded. It seemed as though particles, possibly electrified, were shot off from the carbon walls of the furnace across a space of some 5 or more mm. into the material of the refractory tubes.

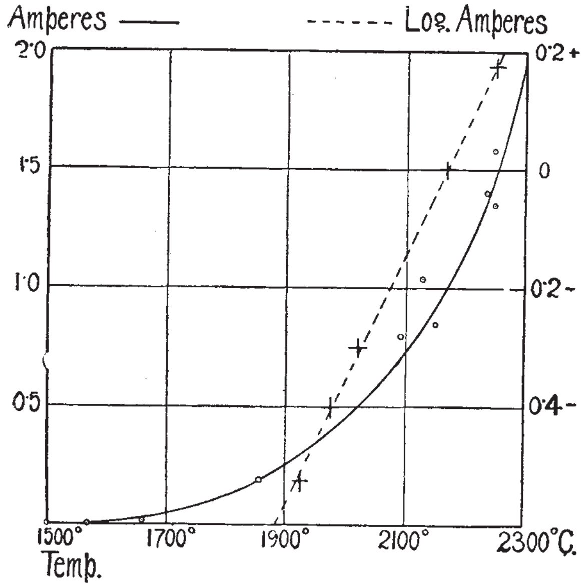

FIG. 5.—The full line curve shows a relation between ionisation current and temperature, for an applied potential of 2 volts on a 1 cm. gap between the electrodes. The dotted straight line is plotted from the log. of the current and the temperature.

Dr. G. W. C. Kaye and I were led to investigate the cause of these phenomena, and yesterday we gave an account of some of the results to the Royal Society. I propose to devote the remainder of my lecture to a description of the methods employed and the results obtained in what proved to be a very interesting investigation.

Many experiments have been conducted, notably by Prof. O. W. Richardson, on the corpuscular emission of electricity from carbon at very low pressures, but scarcely anything is recorded for pressures approaching atmospheric. Positive ions and material particles are also discharged by carbon, as well as by hot metals, at suitable temperatures and pressures.

It is to be understood that in all the experiments now to be described the pressure remained atmospheric, and alternating current was employed for heating. Access of air to the interior of the furnace was prevented by windows at each end, perforated as required.

In the early experiments we inserted within the carbon-furnace tube two insulated carbon electrodes, one of them being hollow, so that a Siemens optical pyrometer could be sighted through it. The two electrodes were joined externally to an ammeter and a battery of cells (see Fig. 2), and we proceeded to determine current-voltage curves at various furnace temperatures. Some of these curves are shown in Fig. 4 for an electrode gap of 1 cm. No appreciable current could be detected below 1400° C. with applied potentials up to 8 volts, but as the temperature rose the current rapidly increased until at 2500° or more currents up to 10 amperes were recorded. At the lower temperatures the currents soon attain what appear to be saturation values. At higher temperatures there is a linear relation between potential and current. As the length of the gap increased the current diminished at a regular rate, but the decrease was small.

Fig. 5 exemplifies the exponential relation between temperature and current for a 1 cm. gap and an applied potential of 2 volts. The dotted straight line was plotted to axes of temperature and logarithm of current.

The magnitude of the currents made it evident that in spite of the high pressure the atmosphere of the furnace was ionised to an unusual degree at high temperatures, and we were led to investigate the effect of temperature alone. The battery was accordingly cut out, and one of the two carbon electrodes was mounted on a sliding carriage so that it could, at will, be moved in or out of the hot part of the furnace, *i.e.* away from the fixed electrode or back towards it. The movable electrode would thus be temporarily cooler than the fixed electrode which remained steadily in the furnace. The ammeter in the circuit indicated a current which amounted to 2 milliamperes at 1400°, and nearly 2 amperes at 2500°; the cooler electrode was the positive one. The currents died away when the two electrodes attained the same temperature.

The production of an alternating current of very low frequency is thus rendered possible by the use of some periodic device. In one form of the experiment (shown) the movable electrode is attached to a crank which, rotated slowly by clockwork, performs the necessary displacement of the electrode within the furnace. The ionisation currents produced are sufficient to make a nest of small glow-lamps light up

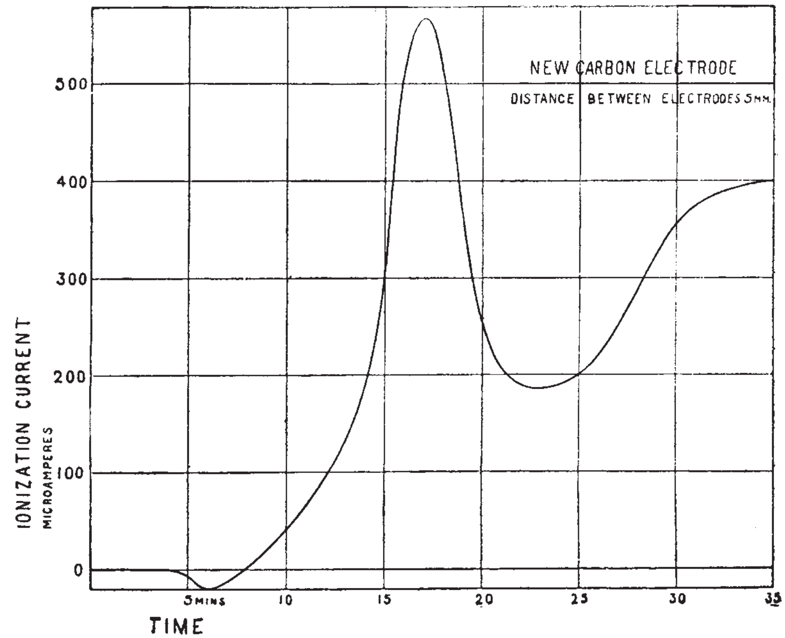

FIG. 6.—Relation between ionisation current and time with a steadily rising temperature. The "cold" electrode was water-cooled; the hot electrode was of new carbon. No potential was applied.

brilliantly, the illumination waxing and waning as the movable electrode moves in and out.

We have been able to repeat some of these results with furnaces of a non-electric character.

In a further series of experiments various modifications were introduced. The two electrodes were replaced by two co-axial tubes, which were mounted within the furnace. The central smaller tube was of brass, through which a rapid current of water was sent; this formed the "cold" electrode. The surrounding larger tube of carbon constituted the hot electrode, and received its heat from the furnace. The electrodes were insulated as before, and into the annular space between them hydrogen or nitrogen was continually passed. No potential was applied, and the currents we obtained with a steadily rising temperature and a new carbon electrode are shown in Fig. 6. It will be seen that there was first a small "positive" current (which would be produced by positive ions crossing from the hot to the cold electrode), which soon changed into a much larger "negative" current (in the usual direction); the intensity of the latter dropped, and then showed a progressive increase with temperature. On taking down the apparatus we found that the brass tube was coated over most of its length with a thick and coherent deposit of carbon, which had evidently crossed over from the hot electrode. Towards one end the deposit was rarer and whitish—presumably silica. We associate the maximum negative current of Fig. 6 with the passage of silicon and other impurities, which are volatilised at about 2000° C. out of the carbon electrode. On a second heating neither positive rays nor a negative maximum was detected, but the ionisation current increased steadily with temperature. The transference of carbon from the hot electrode to the cold may possibly prove to be an explanation, not only of the contamination phenomena which gave rise to these experiments, but also of the comparatively large accompanying currents.

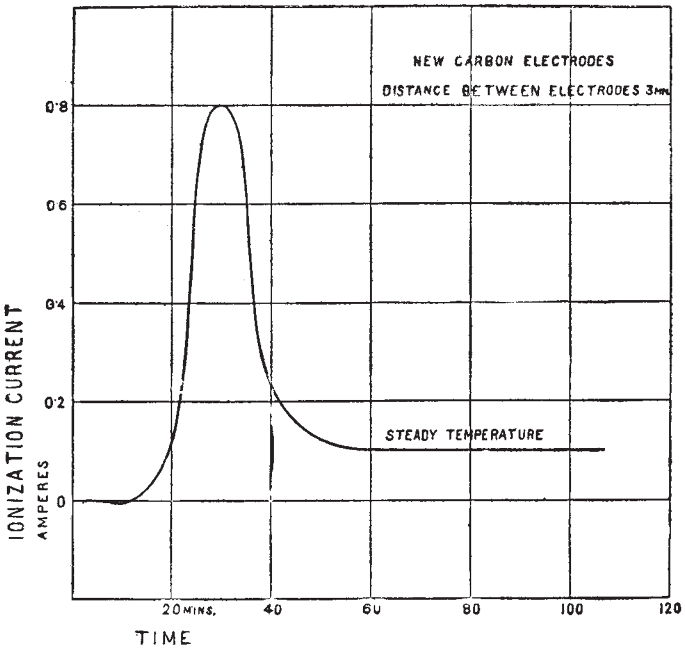

FIG. 7.—Relation between ionisation current and time for two new carbon electrodes, one hot, the other water-cooled. No potential was applied. The temperature was rising for the first fifty minutes, and was afterwards steady.

Fig. 7 illustrates the results obtained when steps had been taken to increase the difference of temperature between the hot and cold electrodes. The carbon was new, and the negative maximum again appears. Afterwards the furnace temperature was steadied, and the ionisation current also kept steady in consequence. It will be noticed that we were now dealing with currents amounting to large fractions of an ampere, and the experiments may fairly be regarded as providing a novel means of generating electricity. Their direct bearing on the problems of the electric arc and the carbon filament lamp is obvious, and we are continuing the research with the view of elucidating the many underlying phenomena.

UNIVERSITY EDUCATION IN GERMANY.[1]

THE development of the German universities during the last hundred years has undeniably raised them in the eyes of the scientific world, but at the same time it has given rise to practical difficulties which are more and more felt, and, here and there, much deplored. German professors regard scientific research rather than teaching as their distinguishing task, or at least their teaching mostly takes the shape of initiation into the methods of research. Their lecturing has thus assumed such an abstract character that the student coming from a higher school in the proud possession of a "certificate of maturity" usually finds the transition to the new atmosphere of thought very hard, and commonly wastes more than one term merely in finding a footing. At the other end, the step from the university into a profession is the reverse of easy; the medical faculty, with its clinical hospitals and similar arrangements, is really the only one which offers a direct training for the future.

A more adequate view of the matter seems, however, to be spreading. In the meantime a year's practical training, complementary to the studies and examinations, has been added to the medical course, and a similar provision has been made for evangelical theology. In the university itself the importance of mental intercourse between the professors and their students is more widely recognised, due to the further development of the university seminaries; even those professors and "privatdocents" who do not conduct official seminaries usually hold so-called "exercises" in addition to their lectures. The throng of students is great on all such occasions; they themselves feel strongly how much less they gain in mental culture from mere listening to lectures. Nevertheless the institution must be regarded as in some respects very incomplete.

In many subjects the seminary deals only with strictly scientific questions (from which the themes for dissertations are frequently drawn), whereas more practical discussions are equally desirable. Besides this the number of those admitted is usually rather small, and indeed not unwisely so, because it is only then that a lively debate becomes possible; a too numerous membership easily tends to make the individuals embarrassed and silent. In most cases, too, only those students are admitted who have already been several terms in the university, whereas it is precisely the freshman who is most in need of help.

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[1] Abridged from an article by Prof. Wilhelm Münch, professor of pedagogy in the University of Berlin, in the Report of the U.S. Commissioner of Education for the year ended June 30, 1911, vol. i., just received from Washington.